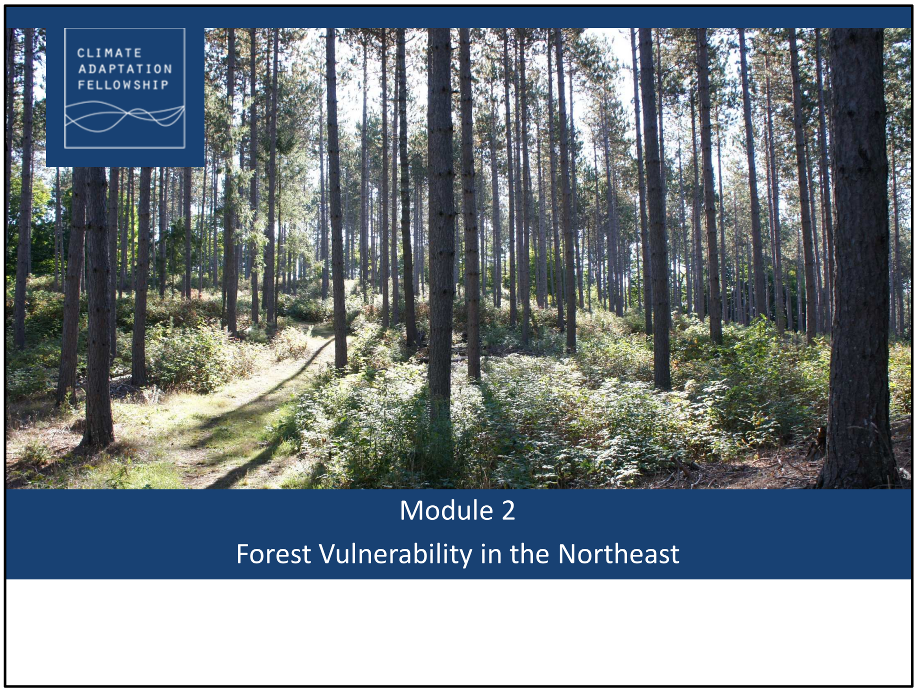


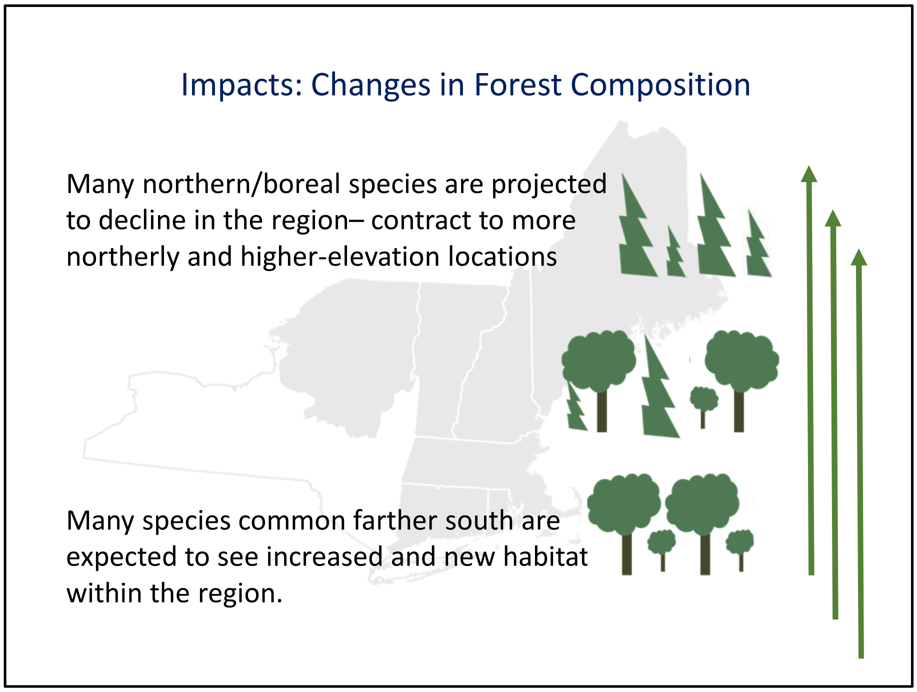
Title slide: presenter can add name, organization, location, date, logos

In this module, we will be covering what a changing climate means for various ecosystem impacts to forests in the region, and how we can take this information into account in order to determine how vulnerable our regions forests are to climate change.

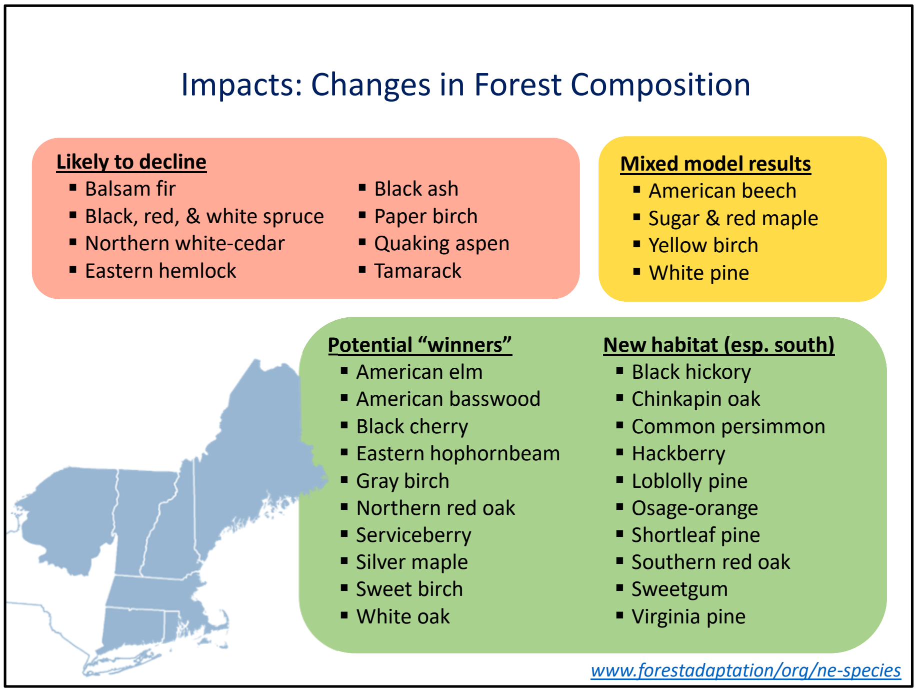
Forest vulnerability in the Northeastern

1. Changes in forest composition
2. Increased frequency of extreme events
3. Disturbance Interactions
    a. Wildfire
    b. Insects & Disease
    c. Invasive plants
4. Vulnerability of forest types
    a. New England forests
    b. Mid-Atlantic forests

There are many types of impacts to ecosystems driven by warming temperatures, shorter winters, and altered precipitation patterns, we are just going to explore a few of those, including potential changes in forest composition, increased frequency of extreme events, and interactions between a changing climate with disturbances from wildfire, insects and disease, and invasive plants. Next we will talk about vulnerability assessments: how they are done, and the results of some of these assessments for our regions various forest types across New England and the Mid-Atlantic regions.



One of the most important impacts of changing climatic conditions in the region is changes to forest composition due to warming and altered precipitation regimes. Many northern and boreal species are at the southern extent of their habitat or are located in high-elevation sites. As temperatures warm, suitable habitats are shifting north or to higher elevations, leaving these location less suitable for these tree species. Similarly, many species common further south will be expected to have greater habitat suitability further north.



Lists of tree species "winners" and "losers" are available for different regions within the Northeast. Here we see the existing species that are likely to decline in habitat suitability, experience increased suitability ("winners"), and species not typically found within the region that will gain new habitat. Multiple models were used to generate these lists. Generally these models agree on changes to habitat suitability, but the species where the models give different results are shown in the "mixed model results" category. This indicates there is some disagreement between models in how these species may be affected by a changing climate.

Impacts: Changes in Forest Composition

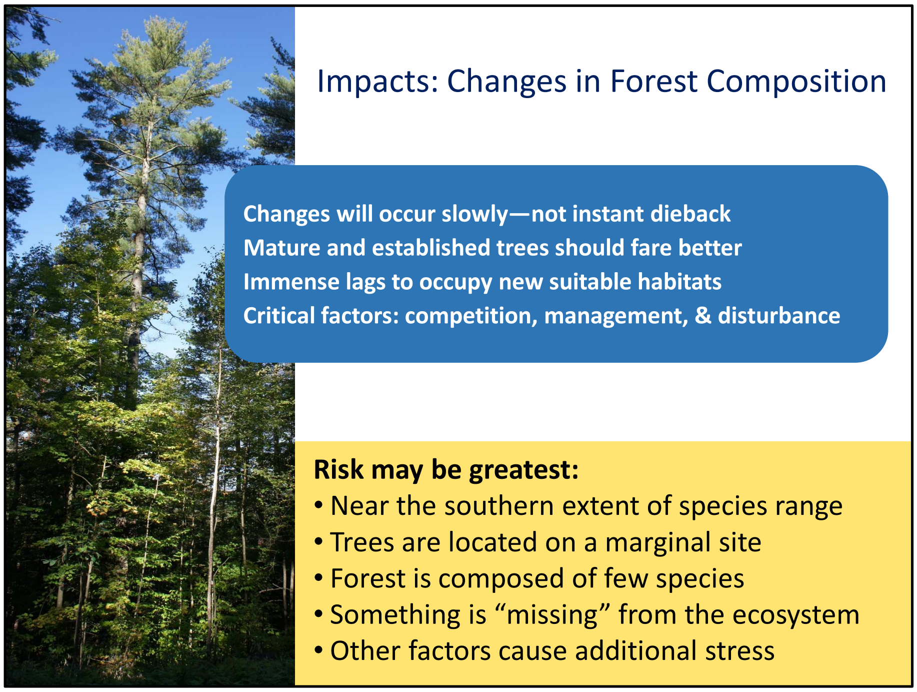
Potential "losers"
- American beech
- Balsam fir
- Eastern hemlock
- Eastern white pine
- Northern white-cedar
- Paper birch
- Quaking aspen
- Red pine
- Red Spruce
- Sugar maple
- Tamarack
- Yellow birch

Mixed model results
- Cucumber tree
- Silver maple
- Sourwood
- Table Mountain pine
- Tulip tree

Potential "winners"
- Black walnut
- Chinkapin oak
- Eastern redcedar
- Flowering dogwood
- Pin oak
- Post oak
- Scarlet oak
- Shagbark hickory
- Southern red oak
- Sycamore

New habitat
- Black hickory
- Cedar elm
- Laurel oak
- Longleaf pine
- Ohio buckeye
- Overcup oak
- Shumard oak
- Slash pine
- Sugarberry
- Turkey oak

Same text as slide 4 – presenter chooses slide based on location



However, these changes will occur slowly, we don’t expect sudden dieback for most of these species. Healthy, mature trees are expected to do better, particularly where competition for light and moisture is limited. Management to reduce this competition can be critical, as is limiting disturbance. Risks for changes in forest composition are greatest where tree species are at the southern extent of their range or where trees are on marginal sites. Factors that increase stress, such as pests, disease, invasives, or salt-water intrusion in coastal forests, will increase risk.

Impacts: Extreme Events

Extreme events may become more frequent or severe

- Heavy precipitation
- Ice storms
- Heat waves/droughts
- Wind storms
- Hurricanes
- **“Events” are not well modeled**

Risk may be greatest: Depends greatly on site conditions and susceptibility to different types of disturbance

Just as heavy precipitation events are becoming more common, so are other extreme events, such as ice storms heat waves, droughts, wind storms, and hurricanes. These events are very difficult to predict, and can be very damaging, causing large losses of healthy mature trees, reducing forest canopy and productivity. The impacts of these storms greatly depend on site conditions, and trees damaged or stressed from other disturbances can be particularly susceptible.

Interactions: Wildfire

Future climate conditions suggest increased risk of fire.

Wildfire may increase if:

- Warmer/drier summers
- Increased mortality from decreased suitability
- Shift toward fire-associated species like oaks and pines

Wildfire may not change:

- Spring/early summer moisture
- Current regeneration of more mesic species
- Spatial patterns of land use and fragmentation
- Fire suppression

Clark et al. 2014, Guyette et al. 2014

Risk may be greatest: Fire-dependent forests or areas of tree mortality when fire is not suppressed.

Future climate conditions increase the risk of wildfire in the region. This may be primarily driven by warming temperatures and drier conditions, particularly later in the growing season. Decreasing habitat suitability for mesic species may result in increased tree mortality rates when wildfires do occur, which may increase the rate of change in some forest type towards more fire-associated species like oaks and pines. However, increasing precipitation, especially in the spring or early summer in some years, may not lead to increased fire risk. This may be strengthened by increasing regeneration of mesic species, such as maples, that reduce soil evaporation. Additional changes in land use and forest fragmentation may further lead to lowered fire risk, especially in combination with fire suppression activities. Overall risk is greatest in fire-dependant forest types or areas where tree mortality are high following disturbances such as a blowdown or severe insect pest outbreaks.

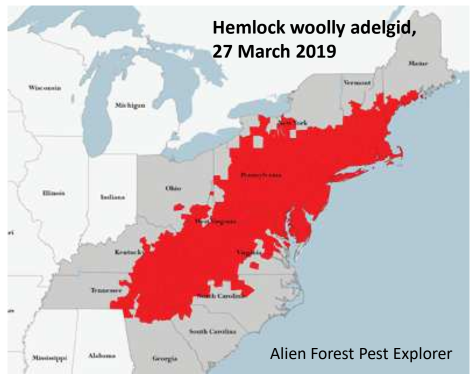
Interactions: Insects and Disease

Increased damage from forest insects & diseases

Indirect: Stress from other impacts increases susceptibility

Direct:

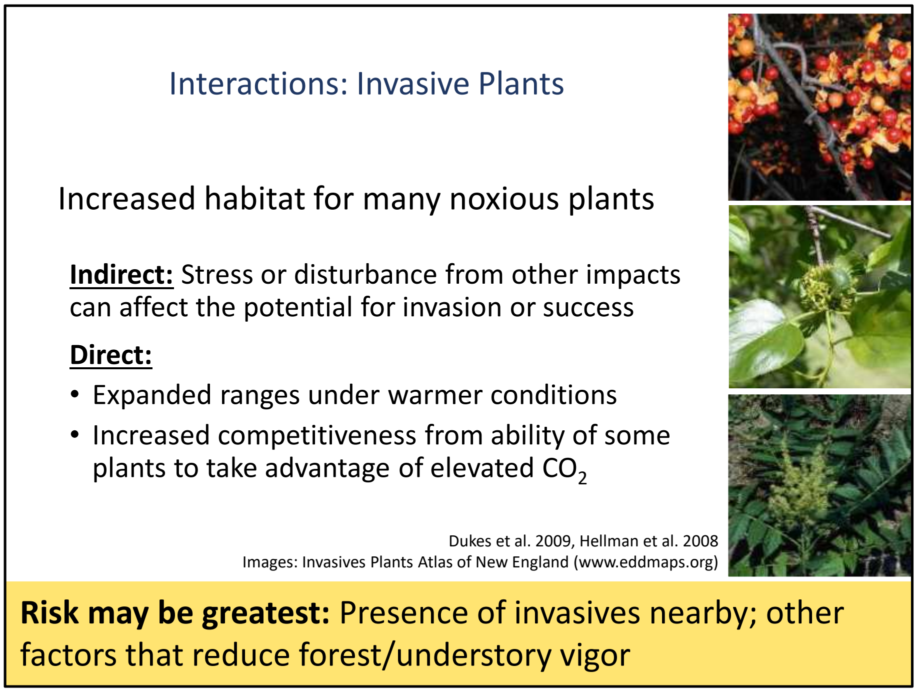
- Pests migrating northward
- Decreased probability of cold lethal temperatures
- Accelerated lifecycles



Ayres and Lombardero 2000, Parmesan 2006, Dukes et al. 2009, Weed et al. 2013, Sturrock et al. 2011

Risk may be greatest: Presence of host species; pest is nearby; other factors reduce forest vigor

A changing climate interacts with forest insect pests and diseases both directly and indirectly. For example, tress that are stressed from other impacts associated with a changing climate, such as wind or ice damage, may have increased susceptibility. These indirect effects may increase the risk of impacts significantly Direct impacts of warming temperatures include northward migration of insects as the probability of lethal cold winter temperatures decreases. Longer growing seasons also can result in increased lifecycles resulting in more than one generation during a single growing season, increasing populations rapidly.



Similarly, invasive plants interact with climate change to effect forests both directly and indirectly. Increased disturbances create opportunities for invasive to colonize new areas that can significantly reduce forest health and regeneration. Like insect pests, warming temperatures can result in northward expansion of species ranges, while other species have increased vigor or reproduction from warming and higher levels of carbon dioxide in the atmosphere.

Climate Change Vulnerability Assessment

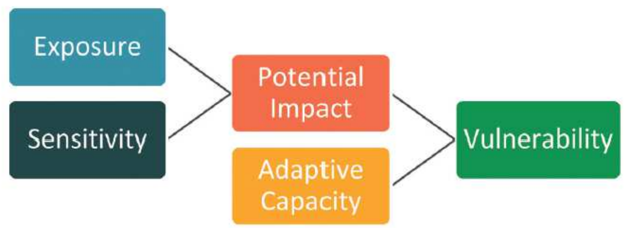
Determination of the degree to which specific resources, ecosystems or other features of interest are susceptible to the effects of climate change, including climate variability and extremes.

Assessments are based on the synthesis and integration of:

- Quantitative analyses
- Peer-reviewed science
- Expert-driven information

Vulnerability is the susceptibility of a system to the adverse effects of climate change. A forest system is considered to be vulnerable if it is at risk of a shift in composition that leads to a substantially different character for the system, or if the system is expected to suffer substantial declines in extent, health, or productivity.

Vulnerability = (Potential impacts) + (Adaptive Capacity)



1. **Potential impact:** The direct and indirect consequences of climate change on a system, based on the combined effects of exposure + sensitivity
   i. **Exposure:** The degree of stress on a system
   ii. **Sensitivity:** The degree to which a resource will be affected by that stress
2. **Adaptive capacity:** The ability of a resource to accommodate or cope with potential climate change impacts with minimal disruption

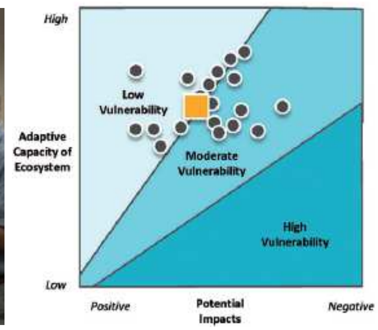
Vulnerability is a function of potential climate change impacts and the adaptive capacity of the system. Potential impacts are influenced by both the exposure of the system to stressors, as well as the sensitivity of the system to those stressors.

Adaptive capacity is the ability of a species or ecosystem to accommodate or cope with potential climate change impacts with minimal disruption. Regional experts summarize factors that could reduce or increase the adaptive capacity of forest systems within the assessment area. Higher adaptive capacity tends to reduce vulnerability to climate change, and lower adaptive capacity tends to increase vulnerability.

Determining Forest Vulnerability

Experts provide a determination of an ecosystem’s vulnerability based on their understanding of a systems adaptive capacity and the potential impacts of climate change (circles).

Groups of experts can come to a consensus on vulnerability through discussion (square).



Here is an example of how the vulnerability determination process works. Experts provide individual determination of an ecosystem’s vulnerability based on their understanding of a systems adaptive capacity and the potential impacts of climate change (these are shown as circles on the figure on the right). Based on this collection of circles, the group of experts then can come to a consensus on vulnerability through discussion (shown as a square in the figure). In essence, this square represents the mid-point, or “average”, of the individual circles.

Vulnerability of New England/ northern NY forest types

Forest system	Potential impacts	Adaptive capacity	Vulnerability	Evidence	Agreement
Central hardwoods	Moderate-Positive	Moderate-High	**Low**	Medium	Medium
Low-elevation spruce-fir	Moderate-Negative	Moderate	**Moderate-High**	Medium	Medium
Lowland and riparian forest	Moderate	Moderate-High	**Moderate**	Limited-Medium	Medium
Lowland mixed conifer	Moderate-Negative	Low-Moderate	**Moderate-High**	Limited-Medium	Medium
Montane spruce-fir	Moderate-Negative	Moderate	**Moderate-High**	Medium	Medium
Northern hardwoods	Moderate	Moderate-High	**Low-Moderate**	Medium	Medium-High
Pitch pine-scrub oak	Moderate-Positive	Moderate	**Low**	Medium	Medium-High
Transition hardwoods	Positive-Moderate	Moderate-High	**Low**	Medium	Medium

Janowiak et al. 2018; https://www.nrs.fs.fed.us/pubs/55635

For each forest ecosystem in the New England region an expert panel considered the positive and negative potential impacts, as well as a variety of factors that contribute to the adaptive capacity of a system. These were then considered collectively to produce a measure of the forest community vulnerability. This slide summarizes the overall vulnerability rating for all forest types within the New England region, with associated ratings of the evidence and agreement.

New England: Montane Spruce-Fir

Moderate-High Vulnerability

medium evidence, medium agreement

Neutral-Negative Impacts:

- Coldest & most extreme climates; sensitive to warming (-)
- Dominant species expected to decline (-)
- Changes in stressors: pests, herbivory (+/-)

Moderate Adaptive Capacity:

- High latitudes and elevations; isolated at southern extent (-)
- Slow to recover from disturbance (-)
- Currently on the rebound; competitive in current location (+)

One example of vulnerability determination is Montane spruce-fir communities in New England. Experts determined that these forest types were generally moderate-high vulnerability to climate change due to neutral to negative impacts along with moderate adaptive capacity. The most important impacts were the negative effects from being located on the coldest and most extreme sites and the species sensitivity to warming resulting in expected declines in habitat suitability. This warming results in mixed effects on forest pests and herbivory, with increases in some stressors and decreases in others. The adaptive capacity of these systems was determined to be moderate, with limited ability to migrate due to high latitudes and elevations, and the species slow recovery rates from disturbance. However experts did note that this community type is currently competitive in their current locations as these systems rebound from previous stressors such as acid rain and previous logging.

New England: Central Hardwood- Pine

Low Vulnerability

medium evidence, medium–high agreement

Neutral-Positive Impacts:

- Northern extent of range; present across diverse sites (+)
- Dominant species expected to persist/increase (+)
- Changes in stressors: pests, invasives, herbivory (-)

Moderate-High Adaptive Capacity:

- Can tolerate/thrive under warm & dry conditions (+)
- Diverse species traits & tolerances; seeding/sprouting (+)
- Fire suppression favors mesic species (-)

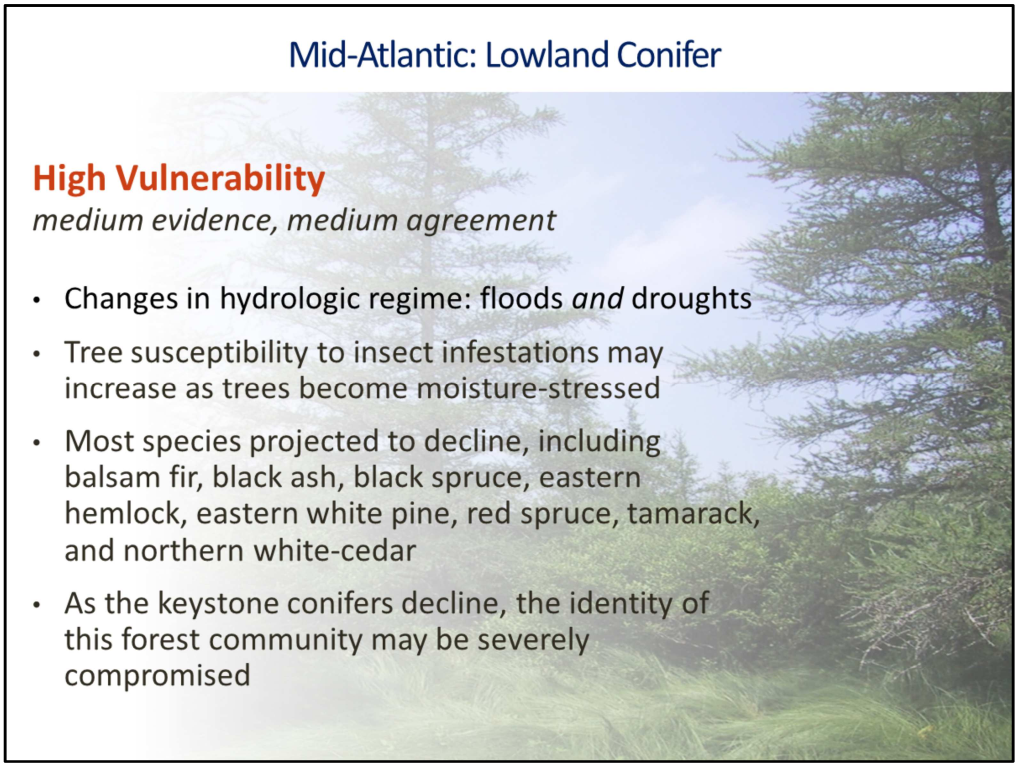
Central hardwood pine forests are at the northern extent of their range in the region, are dry to mesic sites on well-drained soils and are expected to be able to cope with increased risk of wildfire. Although stressors from insect pests, invasives, and herbivory are expected to increase, impacts are expected to overall be neutral to positive. Because thee forest have a diversity of oak and hickory species with diverse traits including drought tolerance and various reproductive strategies, the adaptive capacity was determined to be moderate to high. Fire suppression does favor shade-tolerant mesic species, reducing adaptive capacity where light reaching the forest floor has limited regeneration of mid-tolerant or intolerant species.

Vulnerability of selected Mid-Atlantic forest types

Forest system	Potential impacts	Adaptive capacity	Vulnerability	Evidence	Agreement
Montane spruce-fir	Negative	Low	**High**	Medium-Robust	High
Northern hardwoods	Moderate-Negative	Moderate	**Moderate-High**	Medium-Robust	Medium-High
Central Oak-Pine	Moderate-Positive	Moderate-High	**Moderate-Low**	Medium	Medium-High
Woodland, glades, & barrens	Positive	Moderate-High	**Low**	Medium	Medium-High
Lowland and riparian hardwood	Moderate	Moderate	**Moderate**	Medium-Limited	Medium
Lowland conifer	Negative	Moderate-Low	**High**	Medium	Medium
Coastal plain swamp	Moderate	Moderate-High	**Moderate-Low**	Medium	Medium
Coastal plain Oak-Pine Hardwoods	Moderate-Positive	High	**Moderate-Low**	Medium	Medium-High
Coastal plain Pine-Oak Barrens	Moderate	Moderate	**Moderate-Low**	Medium-Robust	Medium-High
Coastal Plain Maritime Forest	Negative	Moderate-Low	**High**	Medium-Robust	Medium-High

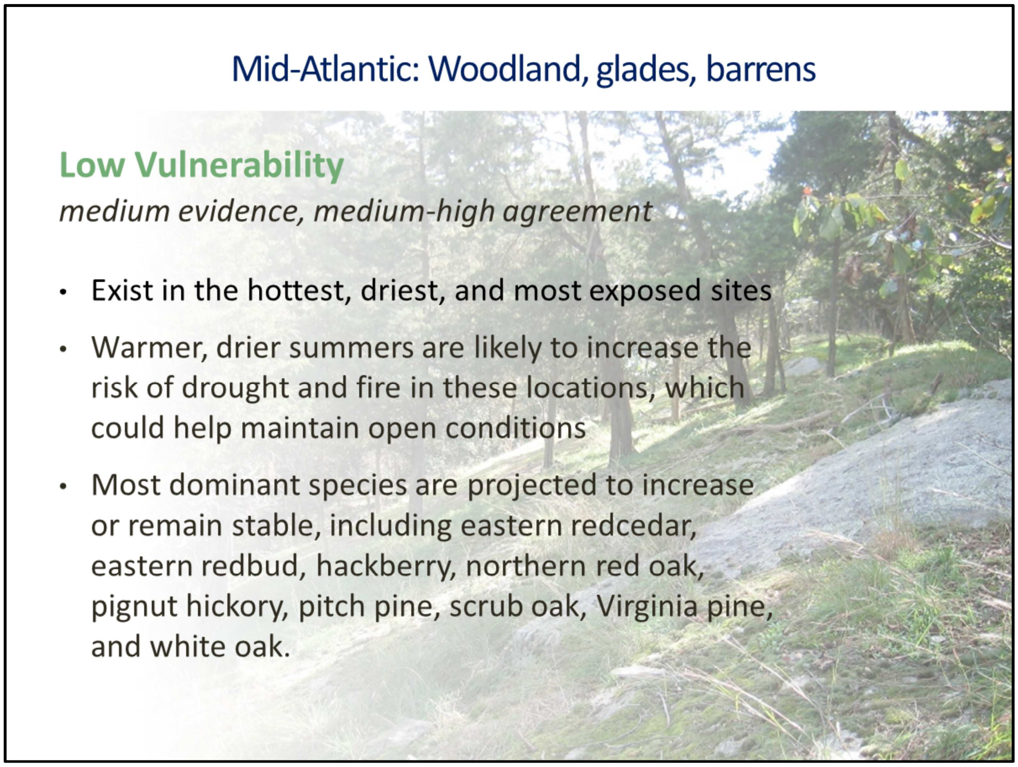
Butler-Leopold et al. 2018; www.nrs.fs.fed.us/pubs/57325

Similar to New England, for each forest ecosystem in the Mid-Atlantic ecoregion an expert panel considered all the positive and negative potential impacts, in addition to adaptive capacity factors to give us a measure of the forest community vulnerability. This slide summarizes the overall vulnerability rating for selected interior and coastal systems in the Mid-Atlantic ecoregion, with ratings of the evidence and agreement.



Impacts on lowland conifer forests are expected to be closely linked to site conditions related to hydrology, soils, and other factors. Although prolonged flooding may exceed the saturation tolerance of some species, an increased risk of drought is also a serious threat to many species. Reduced precipitation in the summer and fall may result in drier conditions, which can negatively affect rain-fed ecosystems. Tree susceptibility to insect infestations is expected to increase as trees become moisture-stressed.

Fewer than a dozen species make up the lowland conifer community, and most are projected to decline, including balsam fir, black ash, black spruce, eastern hemlock, eastern white pine, red spruce, tamarack, and northern white-cedar. The physical structure and function of conifer communities create the shady, cool microclimates where they thrive, and there are relatively few native conifers to fill this functional role. As the keystone conifers decline, the identity of this forest community may be severely compromised.



Woodland, glade, and barrens systems thrive in the hottest, driest, and most exposed sites, including steep slopes of shale and limestone. Warmer, drier summers are likely to increase the risk of drought and fire in these locations, which could help maintain open conditions. However, longer or more extreme drought can delay germination or kill seedlings and mature trees.

This community is characterized by fewer than a dozen species, which vary based on the presence of shale or limestone bedrock. Most dominant species are projected to increase or remain stable, including eastern redcedar, eastern redbud, hackberry, northern red oak, pignut hickory, pitch pine, scrub oak, Virginia pine, and white oak. Sugar maple is projected to decline, and would be the species most likely to disappear from this community type due to moisture deficit.